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Tianfeng Wan

# **The Tectonics of China**

**Data, Maps and Evolution**

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**Data, Maps and Evolution**

With 156 figures, 52 of them in color



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*Author*

Prof. Tianfeng Wan  
School of Earth Sciences & Resources  
China University of Geosciences (Beijing)  
Beijing 100083, China

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## Preface

The theory of plate tectonics was introduced to China in the early 1970s. Over the last thirty years, both Chinese and foreign geoscientists have undertaken many studies which contributed to our understanding of the tectonics of the Chinese continent, by systematically analysing and summarising considerable amount of data accumulated for regional geological surveys, and by improving methods and methods of research. These studies concerned not only the distribution and geometry of tectonic stratigraphic units and their deformation, but also the lineaments, evolution and causes of rock deformation and movement of the lithospheric plates. As a result of these studies, many new and surprising phenomena have been discovered, and many new concepts have also been developed. Research has progressed from purely qualitative assessments of deformation and movement, with the focus on rates of movement measured by numerical calculations providing more quantitative estimates. Concepts have also evolved from the presumption that the Earth's crust is essentially stable to an appreciation of it as in constant movement. These aspects will be discussed in this book.

Tectonics is now an essential component of studies in earth sciences, providing the scientific basis for the discovery and exploration of new mineral deposits and energy resources, the prediction of the environment and the prediction and reduction of the effects of natural hazards. There is an urgent need to summarise systematically the abundant recently acquired tectonic data for scientific research, explanation of mineral deposits and energy resources and the protection of the environment.

The practical and theoretical basis for studies in tectonics is provided by developments in: (1) Regional geological studies; (2) Tectonic models; (3) Methods of tectonic analysis; (4) Concepts of tectonic evolution.

Regional geological studies provide the foundation for the study of tectonics and have been conducted in China since 1949. Regional geological maps at 1:100,000 scale were compiled for the main part of Chinese continental territory in 1940s–1940s and at 1:200,000 scale from 1950s to 1950s (China's national provincial geological maps of China, 1984–1995). Based on these data, tectonic units have been defined, discussed and analysed carefully in each region (Guangdong (1934–1937), also known as Hunan) (Kang, 1948, 1951, 1964, 1980, 1979, 1984, 1985); Gansu and Kweichow (Geology, Heilong College of Geology, 1953); Shaanxi et al., 1980, 1990, 1995, 2000; Jiang and Yang, 1980; Chen et al., 1994; Che et al. et al., 2002). Local and regional tectonic characteristics are now well understood. In Chinese geoscientists recognised larger scale tectonic regions and integrated the regional features into the tectonic development of the Chinese continent can survive better than the geoscientists thought as a whole. However, the use of fixed tectonic units does not provide an appropriate basis for the description of the tectonics of China, as well as the course of tectonic evolution. The effective tectonic units have changed through time.

Tectonic models have provided important concepts for understanding tectonics. Leleux (1889–1977) also known as Leclercq (1926–1997) proposed a structural system based on a combination of the features of rock deformation and the different types of stress (‘epissial’ type 1 (for ‘obolent’) type

linear structural system; parallel structural system; longitudinal structural system; frame structure system, etc.). However, this classification will not be used in the following chapters.

Most recent monographs and textbooks on tectonics (e.g. Currier, 1992, 1993; Kearney and Yin, 1994; Van der Plighe and Marsh, 1994; Doreks, 2001; Brackley, 2001) used the same tectonic models: convergent tectonics (subduction, collision, indentation) and mass belts; Divergent tectonics (oceanic ridges, rifts, extension, basins, detachment) and metamorphic zone complexes; transform tectonics (transform and strike-slip faults); Inversion tectonics (active or earlier tectonic systems). The theoretical system emphasizes the mechanism and the components of each tectonic model, and is easy to be understood. However, this system does not place much emphasis on tectonic history. The system emphasizes the tectonic analysis of specific geological situations, but it is important to realize that geological sciences is essentially a historical science, and that many changes and many different tectonic events have affected the lithosphere from more than four billion years of Earth history.

It is not in our opinion for us to restrict to the methods of tectonic analysis. However, only emphasizing the methods but never discussing the tectonic evolution in detail, as McW.P. (1992) did, has been proved ineffective.

Many monographs and papers emphasize the historical aspects of the tectonics of China have been published by Lin (1971, 1981, 1984, 1986, 1987, 1988, 1989), Liu (1981, 1982, 1984, 1989), Wang (1982, 1983, 1984, 1989), Ren (1988, 1991, 2003) and Kohn and Hodson (1993).

Here such as the concerned with "Historical Tectonics". On one hand, specialists engaged in historical tectonics pay more attention to structure type and the characteristics of geological formations and their origins, and analyze their lithological and paleontological characteristics, their geographic environments of formation and the origins of the sedimentary sequences, with emphasis on their historical evolution. On the other hand, tectonic modelers pay more attention to the transformation of rock bodies, the rock deformation, structural geometry, the stress and strain states, the habitats on the mechanism of deformation. Although most researches engaged in tectonics agree that both geological formation and transformation should be studied, and that historical and mechanical analyses should be combined, due to the deficiencies of the long experience and the focus of their interests, these different approaches may have different advantages. Zhong WY (1992, 1994) and Li (1993, 1995) indicated that these approaches should be integrated in the study of the tectonics of China. The author considered that it is really important for geological research precedents in the present volume, though it is very difficult.

In this book, the author does his utmost to combine the studies of formation and transformation using the plate tectonic theory, together with historical and mechanical analyses. Abundant and recently reported geological, geochronological and geophysical research data are applied to describe and discuss the sequence of tectonic events which have affected the Chinese continental lithosphere from the Archean to the Recent. Until the present time, it is difficult to achieve this aim because of the scarcity of data on the tectonic evolution.

In this volume, for understanding the tectonics of China, the author puts forward many new views: calculation of the thickness of the continental crust of the Sino-Korean plate and the Australian and Antarctic plates to determine the velocities during motion the Supercontinent of Gondwana; the continental blocks were amalgamated to form the Chinese continent, establishing the plates during the Mesozoic; the Sino-Korean and Yangtze plates respectively following the changes of the meridional and longitudinal distribution of the Chinese continental blocks during the Paleozoic. During the Late Paleozoic, most of the continental blocks were convergent to the China craton and were connected with the Eurasian Plate. Subsequently China continent was affected by intra plate deformation with three series of shortening in the North-Southern and Eastern Period (260-230 Ma), Sichuan Plate Period (220-200 Ma), Hainan Plate Period (140-130 Ma) two periods of shortening with a north-west-south-east Period (120-85 Ma), North-South-South Period (60-25 Ma). Since 100 Ma (Quaternary Period), the state of stress among the plates which constitute the Chinese continent has been nearly in equilibrium.

In this volume, the characteristics of many collision zones in the Chinese continent are analyzed in detail and discussed. The type of the thickness of the crust and the lithosphere beneath

is proposed for the "main body" of the *U-hat* sphere beyond the eastern Asia continent, which is possibly induced by the counterbalancing reaction of the continental crust extension to compressive tectonic motion. The origin of the environment by reaction is recognized; the influence of tectonic extension on driving the Mesozoic Cretaceous on periods of low or no neovolcanism in China is made understandable; the two hypotheses about the dynamic mechanism that control global tectonics are evaluated.

This book was originally written by the author in Chinese and published by the Geoscientific Publishing House in Heilong in 2014. After incorporating many constructive comments, the book was translated into English, with a reduction of local terms and the removal of discussions which were not necessary to the foreign readers. Through translation, emphasis has been placed on areas such as features and the major tectonic zones which have affected the Chinese continent. A new series of preliminary maps have been prepared following the suggestions of experts in specified fields. For the sake of the foreign readers, the articles and long titles of critical features have been translated. Original data are recorded in Appendices, and a large number of references are cited, particularly from the Chinese literature, to facilitate further research in Chinese literature.

Hanfeng Wu  
Jelonek, October 2014

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Although the preparation of this book is the responsibility of the author, it clearly represents the collective literature and scientific creation of many researchers, colleagues and friends. I would like to express my heartfelt gratitude for their invaluable help and guidance.

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## Chapter 1 Introduction

Tectonics is a comprehensive subject area involved in Earth sciences concerning the historical development, evolution and origin of the earth. The aims of this subject are to determine the composition, the structure, the movements (tectonic deformation and displacement) and the evolution of the inner sphere of the solid earth, the lithosphere, and its relationship to activity in the interior, in the lower mantle and the core. This subject area is encompassed in the Theory of Plate Tectonics originating from the investigation of the ocean floor's structure, and combined with the theory of continental tectonics which until then had not universally accepted, evolved into a comprehensive theory of global tectonics (Kuo 1977).

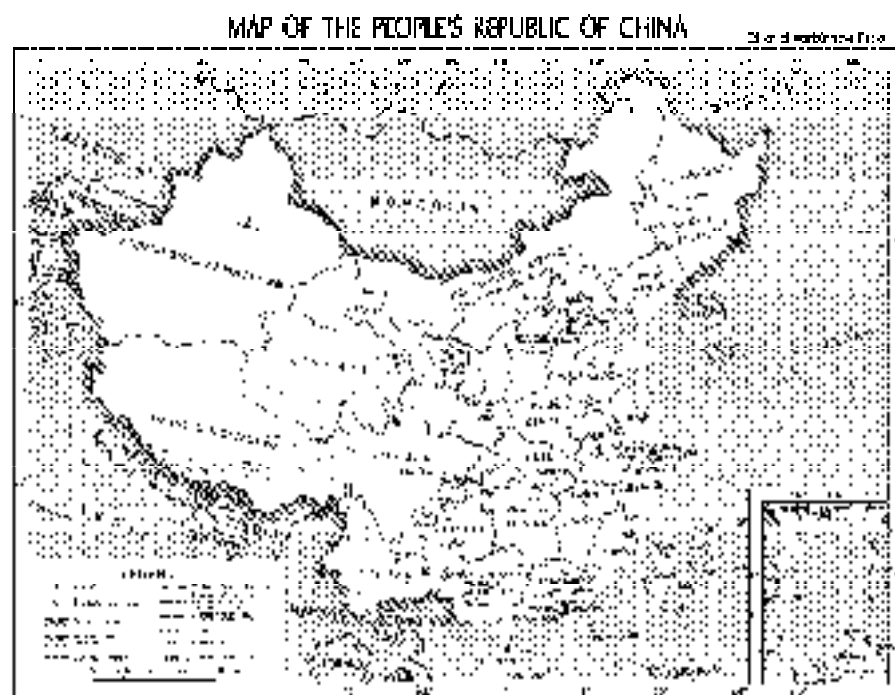


Fig. 1.1 Geological map of the People's Republic of China, with annotation of tectonic units (Springer-Verlag, Beijing, China).



development of this subject area, encourage the cooperation of specialists involved in all the geoscience disciplines in the construction of a comprehensive Earth Sciences system.

In this book, the tectonics of China (Figs. 1.1 and 1.2) is dealt with as a sequence of tectonic events through geologic caltime. A comprehensive analysis of these events is based on the interpretation of records preserved in the rocks, which provides the evidence of the deformation produced by the movement of continental blocks during processes of the subduction, collision and finally convergence or the extension.

The tectonic systems developed out of these events are described in terms of rates of movement, orientation of tectonic stresses, major tectonic stress, and the nature and type of deformation. These tectonic and structural aspects are interpreted, together with the tectonic sedimentary, tectonic paleogeography and tectonic geomorphology, in the distribution of continental blocks and tectonic geological periods based on paleogeomorphology and deformation of paleogeographic units data. As far as possible, these aspects are dealt with in a quantitative and a purely qualitative manner.

The Chinese continent is located in Eastern Asia (Fig. 1.1), composed of the Qinshui-Kangursi Plateau, the Inner Mongolian-Uralian-Sunnan-Guizhou Plateau, the Dabai Mountains and Inner Mongolia Plateau and their surrounding mountains, and the eastern plains and hills. Generally, the Chinese continent consists of large continental nuclei and small blocks, which were gradually amalgamated to form the present Chinese continent. Unlike the Paleozoic-Geotectonic blocks had been identified in the Chinese continent (Fig. 1.2) had been divided into five tectonic domains, which will be discussed in detail in later chapters. The evolution of the Chinese continent was very different from the evolution of the North American, South American, Eurasian, African and Australian continental plates.

## 1.1. Tectonic Events

**Concept:** Before discussing tectonic events it is necessary to introduce the concept of the tectonic stratigraphic unit (or tectonic period) originally proposed by geologists of the Soviet Union in the 1940s and introduced to the study of the tectonics of China by Zhang RY (1960). American geologists have also used a similar concept, the "tectonostratigraphic unit" more recently (Blümelberger and Harvey, 1996).

A tectonostratigraphic unit encompasses all the tectonostratigraphic features of a tectonic unit, distinctively by a particular type of deformation developed out of a particular tectonic period. In terms of time, a tectonostratigraphic unit represents a period in the tectonic evolution of the earth's surface in which it covers the area affected by a specific tectonic event (Fig. 1.2).

The boundary of a tectonostratigraphic unit is taken as a base of the sedimentation, marked by a regional angular unconformity which separates two tectonostratigraphic units (Fig. 1.2). The tectonostratigraphic unit lies between two angular regional unconformities. An angular regional unconformity is formed when an older rock unit deformed by either compressive or extensional is then uplifted, eroded and buried by younger rocks. The boundaries of tectonostratigraphic unit should not be taken as parallel unconformities or disconformities, as these do not represent significant tectonic events.

Different tectonostratigraphic units are characterized by different rates, styles and degrees of rock deformation, with different intensity, resulting from different stress orientations in different tectonic environments (Fig. 1.1). The geochronologic time occupied by a tectonostratigraphic unit is a "tectonic period". Each tectonic period can be divided into a stable (or "quiescent") period, which lasted for a relatively long series of time, and an active (or "catastrophic") period which occupied a much shorter period of time at the end of the tectonic series (Table 1.1). Each tectonic period commences with a long and stable period and ends with a short and active period. Movement of blocks, rock deformation and the related metamorphism and magmatism mainly constitute a tectonic event over the shorter and active tectonic period. By convention, these tectonic events are named after the area in which the tectonostratigraphic unit first occurs used. However, for these events are named after their neotectonic or geomorphic evolution

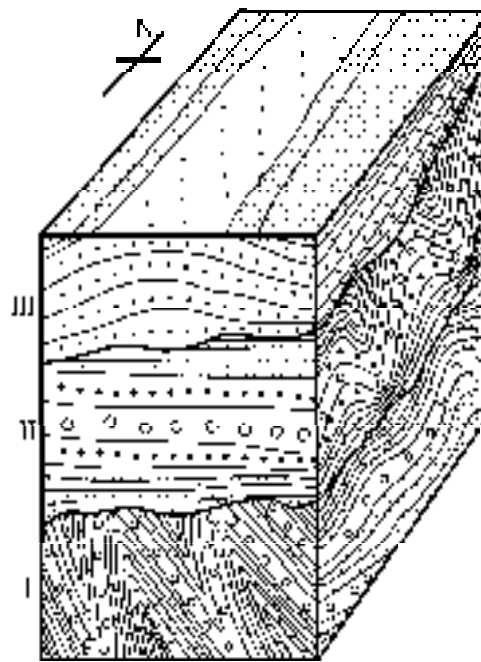


Fig. 1.5. Three-stage tectonic evolution of a continental block (simplified by V. V. Kozubko, 1990)

I. Early orogenic lineation (see 1.4.6.6) developed in a fold structure of a minor tectonic unit with a north-stalled collision plate (not shown) by colliding with an SW-orientation of a major tectonic plate.

II. Transition of a major tectonic block developed in a fold structure of a minor tectonic unit (see 1.4.6.6).

III. Stage of a continental block developed in the course of tectonic shortening of a major tectonic unit (see 1.4.6.6).

interfacial comparison becomes easier. Conventional terms, derived from local tectonic periods or local events, are therefore used as far as possible in this book.

The degree and style of tectonism are different in the active and passive periods, but there is usually some connection and dependence, for example, the orientation of tectonic stresses and the direction of plate movement may be the same in both periods. However, the styles and rates of rock deformation are very different and the mineralogies of the rocks are different and the types of magmatic activity and metamorphism are also different (Table 1.1).

## 1.7 Universal Tectonic Periods

Smith (1836–1846) proposed that there was a rhythm in the tectonic evolution of the Earth and that geological history was characterized by successive periods (which he called “phases”) which occurred at the same time in different parts of the world. In the 20th century this principle exerted a great influence on the development of tectonics. It has been used continually and reverse since it was first put forward. The concept of a universal tectonic period was considered that rock deformation increased dramatically with changes in the plate tectonic forces of geological time (see, for example, 1964), and some American geologists (e.g. Gilluly, 1949) even distinguished with the concept of phases of universal orogeny, but





and their destruction of subduction zones along the margins of the oceans, it could easily be assumed that the processes of subduction and collision were also continuous processes. However, Linné (1989) and Bengtson (1992) hypotheses considered many disjunct tectonic roots before 1990's. When the much more detailed third edition of the tectonic-analytic map was published at the end of the 1990's (Cande et al., 1999; Cande and Kent, 1992; Vogt et al., 1993), analysis showed that since the White Cliffs event (500 Myr ago), tectonic plates had all expanded during the same six periods, with movements in different directions and at different velocities (Table 1.2) (Fig. 1.4). Sea floor spreading at velocities of several cm/y shows that the earth has the properties of a neo-plastic solid, while the processes at some periods, such as the one with dimensions are so small extended to reach generally continental and oceanic crust elements or plate tectonics.

Evidence compiled in this volume shows that the tectonic evolution of the earth has not become linear with a uniform rate of change, but non-linear with periodic variations in the rate of change. The only present evidence it appears that the processes continue over a period of time at a more or less constant rate, but are then interrupted by sudden and catastrophic changes. Such qualitative and quantitative changes are characteristic of all evolutionary processes. As in Cande (2003) has explained tectonics, like all other geological processes, then it is considered in terms of non-linear dynamics in a probabilistic system. The evolution of the Earth system then can be studied in the same way as the chaotic theory.

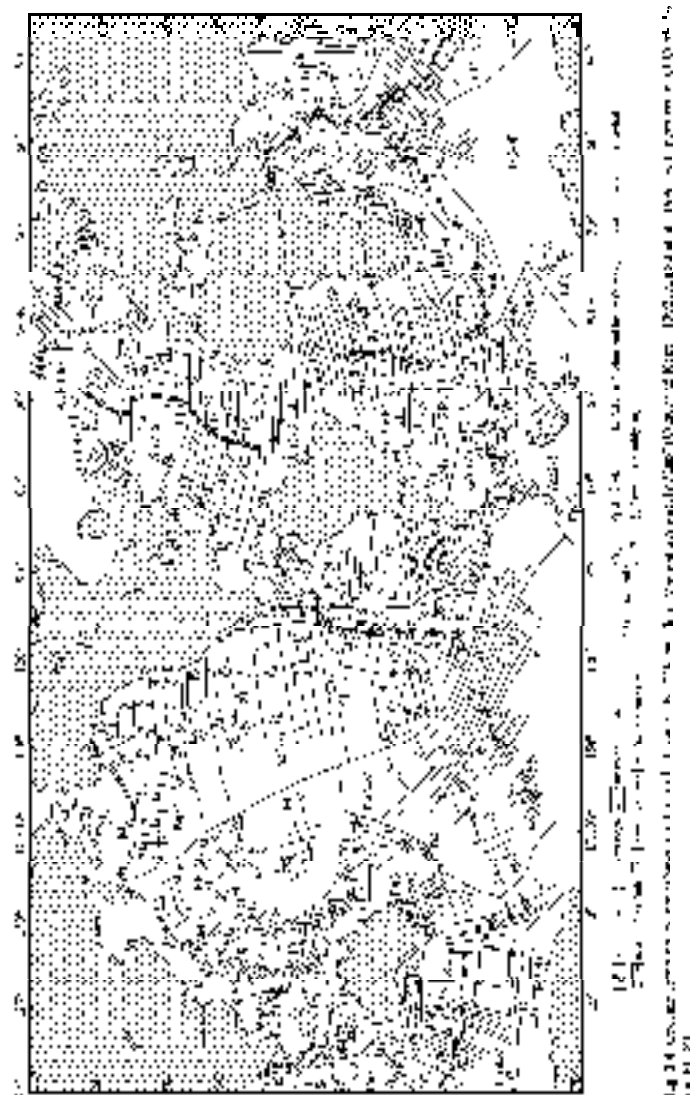
In the past two hundred years, there has been a lively tectonic debate between proponents of minor movements, who argue that geological processes have continued in much the same way and at the same rate in the past and evolutionary time (Humboldt, 1805; Lyell, 1830-1833) and proponents of catastrophism who believe that geological processes proceed by infrequent but catastrophic events (de Cuvillier, 1810). At present, most Earth scientists agree that wise concerns can be reconciled. It is recognized that there are such periods for periods of infrequency last for several long time span, which is the time with derive for catastrophic events, occupies a much shorter time span (Cande et al., 1999) tectonic events represent this catastrophic period (Table 1.1).

Tectonic events are different from the complete history of a tectonic presented in the geological record. The evidence is never complete, shows deformation, block displacement, vicarious tectonism and large scale uplift of the Earth's surface have resulted in widespread erosion, forming unconformities where the geological record has been destroyed. For this reason the study of tectonics did not advance very rapidly in many years of the world. In many areas, facts are few, tectonic and geodynamic data are scarce; the tectonic evolution demonstrates that these deficiencies can be corrected from a long-term in much speculation and guesswork.

Table 1.2. Evolution of the evolution of the earth during the Cenozoic. All times in million years.

0 - 0.5	2.5 cm/y
0 - 5	1.5 cm/y
5 - 10	4.5 cm/y
50 - 60	1.5 cm/y
90 - 100	3.5 cm/y
130 - 150	1.5 cm/y
200 - 250	1.5 cm/y

After modified from 1999 (Cande et al., 1999)



### 1.3 Determination of Tectonic Events in the Chinese Continent

Geological data from whole China recorded in the Bureau of Geology and Mineral Resources of the PRC (1954–1959), the *Geological Gazetteer of China* (Geological Editorial, 1994) and the earlier researches of the author (1994) are referred to the international tectonic chart (Reynolds et al., 2003; International Commission on Stratigraphy, 2004) to compile as a table of the tectonic periods and tectonic events in China (Table 1.3).

The former practice of referring the tectonic periods in China to world-wide tectonic periods is incorrect. A division into tectonic zones and events has been revised purely for the Chinese continent.

Table 1.3. Periodic tectonic and/or seismic movement

Geochronological units	Geological base	Duration of movement (ka)	East or west (mm/ka)
Q <sub>1</sub> -Q <sub>2</sub>	Black Mountains - Alabama	since 195	Westward
Q <sub>2</sub> -Q <sub>3</sub>	Black Hills - Montana	75 - 170	Eastward
Q <sub>3</sub> -P <sub>1</sub>	Basin - Missouri	90 - 91	East Side
P <sub>1</sub> -P <sub>2</sub>	200 Myrs of Early Cretaceous - Eocene	135 - 76	Westward
P <sub>2</sub> -P <sub>3</sub>	100 Myrs of Early Cretaceous	100 - 35	Eastward
P <sub>3</sub> -T <sub>1</sub>	Low Tertiary - Paleocene	90 - 240	Westward
T <sub>1</sub> -T <sub>2</sub>	Black Deceiver - North America	90 - 90	Westward
T <sub>2</sub> -T <sub>3</sub>	Sioux - Dakota - Black Deceiver	90 - 90	Eastward
T <sub>3</sub> -T <sub>4</sub>	Blackburn - Black Deceiver	90 - 90	East
T <sub>4</sub> -T <sub>5</sub>	Lawrence - Norman	90 - 90	West
T <sub>5</sub> -T <sub>6</sub>	Texas	1400 - 90	Eastward (China)
P <sub>1</sub> -P <sub>2</sub>	France - Sicily	1400 - 1,200	East
P <sub>2</sub> -P <sub>3</sub>	Albania - Sicily	1,300 - 1,100	Westward
P <sub>3</sub> -P <sub>4</sub>	Sicily - Sicily	1,100 - 1,000	Eastward (Italy)
P <sub>4</sub> -P <sub>5</sub>	Albania	1,000 - 1,000	East
P <sub>5</sub> -P <sub>6</sub>	Albania	1,000 - 1,000	East
P <sub>6</sub> -P <sub>7</sub>	Albania	1,000 - 1,000	East
P <sub>7</sub> -P <sub>8</sub>	Albania	1,000 - 1,000	East
P <sub>8</sub> -P <sub>9</sub>	Albania	1,000 - 1,000	East
P <sub>9</sub> -P <sub>10</sub>	Albania	1,000 - 1,000	East
P <sub>10</sub> -P <sub>11</sub>	Albania	1,000 - 1,000	East
P <sub>11</sub> -P <sub>12</sub>	Albania	1,000 - 1,000	East
P <sub>12</sub> -P <sub>13</sub>	Albania	1,000 - 1,000	East
P <sub>13</sub> -P <sub>14</sub>	Albania	1,000 - 1,000	East
P <sub>14</sub> -P <sub>15</sub>	Albania	1,000 - 1,000	East
P <sub>15</sub> -P <sub>16</sub>	Albania	1,000 - 1,000	East
P <sub>16</sub> -P <sub>17</sub>	Albania	1,000 - 1,000	East
P <sub>17</sub> -P <sub>18</sub>	Albania	1,000 - 1,000	East
P <sub>18</sub> -P <sub>19</sub>	Albania	1,000 - 1,000	East
P <sub>19</sub> -P <sub>20</sub>	Albania	1,000 - 1,000	East
P <sub>20</sub> -P <sub>21</sub>	Albania	1,000 - 1,000	East
P <sub>21</sub> -P <sub>22</sub>	Albania	1,000 - 1,000	East
P <sub>22</sub> -P <sub>23</sub>	Albania	1,000 - 1,000	East
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P <sub>40</sub> -P <sub>41</sub>	Albania	1,000 - 1,000	East
P <sub>41</sub> -P <sub>42</sub>	Albania	1,000 - 1,000	East
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P <sub>96</sub> -P <sub>97</sub>	Albania	1,000 - 1,000	East
P <sub>97</sub> -P <sub>98</sub>	Albania	1,000 - 1,000	East
P <sub>98</sub> -P <sub>99</sub>	Albania	1,000 - 1,000	East
P <sub>99</sub> -P <sub>100</sub>	Albania	1,000 - 1,000	East

and these have been given local names (Table 1.3). However, in order to simplify the terms, and for ease of international comparison, the periods and events in this book are named directly after the geological or tectonic ages and local names for tectonic periods or events whenever possible.

As shown in Table 1.3, tectonic periods and events are defined. The extent of our knowledge concerning these tectonic periods and events is very variable. In general, much less is known about earlier periods compared with the more recent ones. Tectonic periods and events in the Caribbean and Pangean are almost completely unknown and periods and events in the Paleozoic can only be discussed generally, and although a series of events can be recognized, the geological data are very detailed and only two periods can be distinguished. The eight tectonic periods and events since the Paleozoic have been researched in much more detail, and as geological data are more abundant and more accurately known, one chapter is devoted to each of these periods.

In the Arabian and Pangean, in the absence of detailed tectonic data, geological ages are defined in terms of tectonic units and, for the divisions are based on the tectonic-magmatic evolution of the continental crust. In the series, since the Eocene, geological and tectonic ages or the commencement and close of each tectonic period do not coincide with the beginning and end of a tectonic period based on biometric data, and the time spans occupied by each tectonic event may be very different (Table 1.3). This is because the start and end of tectonic periods in China did not occur at

the same time as the extinction events indicated by the biostratigraphy; the climax of a tectonic period is always later than the end of corresponding extinctions.

For example, according to isotopic data from sedimentary carbonates in most areas of Utah, as shown in Table 1.1, 134 Ma is the most suitable age for the boundary between the Yanshanian and Eocene tectonic periods. In the international stratigraphic chart (Krause et al., 2000; International Commission on Stratigraphy, 2004), there are different opinions on the age of the boundary between the Jurassic and Cretaceous, ranging from 135 Ma to 146 Ma. From recent studies, most Chinese researchers accept the boundary between Jurassic and Cretaceous as either 137 Ma or 144 Ma (Li, 2000). For the age of the boundary between Jurassic and Cretaceous, the author agrees with the opinion of Li (2000), that is, the boundary between the Yanshanian and Eocene or the tectonic period lies between early and middle Eoethen of Early Cretaceous. According to (Krause et al., 2000), the age of the boundary between the Jurassic and Cretaceous for this case has not yet been reconsidered.

## 1.4 Research Principles and Methods for Interpreting Tectonic Events

### 1.4.1 The Rock Record

The study of tectonic events in the active and stable periods of tectonic evolution requires different research methods. Evidence for the active period of tectonic events is commonly preserved in the rock as structural features such as folds, faults, thrusts, joints, relations and lineaments, which may be accompanied by metamorphism as a process of metamorphism. The original changes in a rock body or in a hand specimen can be expressed in terms of the amount of deformation or strain it has undergone, i.e. reduction or expansion in volume, shortening or extension. Strain can be determined with respect to changes in the length of three mutually perpendicular principal axes of strain ( $\epsilon_1$ , maximum extension, and  $\epsilon_2$  shortest direction;  $\epsilon_3$ , intermediate;  $\epsilon_4$ , minimum compression). The largest extension  $\epsilon_1$  and  $\epsilon_2$  may be equal or have any value intermediate between  $\epsilon_1$  and  $\epsilon_2$ . Strain can be measured if the rock contains 'strain markers', objects whose original size and distribution and orientation are known and can be compared with their present size or shape (Gottschalk and Jünger, 1971).

Tectonic events may also be recorded indirectly by the tectonic sedimentation. Tectonic events are commonly accompanied by uplift and subsidence, erosion, so that the sedimentary record is disrupted. However, the tectonic events may be deposited in marginal depressions or basins or in highly deformed areas as valleys or flysch (Baltica mountains), providing a record of episodes of uplift and erosion. Tectonic events may also be accompanied by the intrusion of magmatic rocks with synchronous alteration and associated hydrothermal metamorphism.

The study of sedimentary strata can be used to solve many problems in tectonics, such as the sedimentary facies and the sequence of formation in stable basins, for the recognition of unconformities and of episodes of strong deformation in the active tectonic period. These studies are part of a complete study of tectonics.

Methods used in the analysis of sedimentation and paleogeography are more appropriate to the stable period of a tectonic structure unit. A stable tectonic period is represented by the deposition of a continuous sequence of sedimentary strata in a tectonically stable basin. During the stable period, variations in the thickness and rates of deposition of sedimentary strata, and changes in the rate of vertical motion of the Earth's crust, such as depression or uplift, can be recognized. By determining the sequence of strata and the rates of each sedimentary unit, it is possible to place these periods of uplift and depression in a chronological sequence and to estimate them. The stratigraphical methods of measuring the thickness of sedimentary strata and determining rates of deposition since the Mesozoic period, as shown in Appendix 2, are very approximate. There is no method of measuring the effects of tectonic depression and uplift

through great thicknesses of sedimentary rocks are most likely to be the results of multiple phases of deflexion and sedimentation and uplift-erosion. Also no allowances have been made for the effects of compaction and diagenesis, or for the influence of subsidence stress caused by later tectonic events. The study of sub-sea-mechanical faults is useful to determine the history or development of sedimentary basins during a stable tectonic period. A complete calculation to the account of all these factors involves an enormous amount of observations, field and laboratory work.

Although a large part of sedimentary rocks, amounting to several tens of thousands kilometers, extends over the major part of the Chinese continent, the greater part of the sediment originally deposited on the continent has been eroded away and is no longer preserved. According to statistical calculations by Kooze et al. (1984, after Durr, 1911, 1926), based on the thickness and extent of sediments and the geological ages of present-day sedimentary basins, deposited since about the world at a rate of 50–100 m<sup>3</sup> per year. Mesozoic-Cenozoic sediments have been preserved on the Earth's surface, of which 50% is from the Paleozoic, 30–35% from the Proterozoic, and less than 15% from the Archean.

The accumulation of tectono-geographical data and especially the reconstruction of ecosystems are important for determining tectonic plate evolution and sub-plate crustal blocks. The reconstruction of paleogeographies demonstrates the continental tectonic plates through time and supports the tectonic concept of tectonics.

### 1.4.2 The Geometry of Rock Deformation

The foundation of the study of tectonics is the determination of the distribution and mutual relationships of rock units as seen in the field, together with their internal structural features such as folds, faults, lineations and foliations. Tectonics involves rock deformation on all scales from the megascopic to the microscopic, from the lithospheric scale to the individual mineral crystal and molecular lattice scale. It interrelates and then is integrated into a comprehensive tectonic system (Fig. 1.4.1). Tectonics is also concerned with the imprints on the excavation of igneous rocks and the metamorphism and the recrystallization of rock bodies with the formation of new minerals and new textures, and the relationship of these events to phases of deformation. These relationships must initially be established in the field by detailed geological mapping and geological structural surveys, sample verified by drill core and by deep structural fluid inclusion geochemical methods and by the study of rocks under the optical and electron microscopes.

The deformation and the displacement of the lithosphere are the main contents of the study of tectonics. Although comprehensive methods should be used in the study of tectonics, and research should encompass all branches of the geosciences, the study of rock deformation should be made on the basis of precomparative tectonics, which has been neglected in some recent studies.

Contributions to the knowledge and understanding of rock deformation in China during the last fifty years have been immense. It can be attributed to the exertion and success of regional geologic calibrations.

In addition to an ample geological survey covering the whole Chinese continent, total geologic charts of million square kilometers at the scale of 1:1,000,000, commenced, but not completed before 1949, and regional geologic surveys of regional geology at the scale of 1:200,000 was completed in the 1960s (for amphibious survey), a regional geologic survey at the scale of 1:200,000 was carried out for most areas of China before the end of the 1950s (Bureau of Geology and Mineral Resources of PRC, 1994–1995). In new regional geologic calibrations at the scale of 1:200,000 (more than 100 areas) has been completed recently over whole Qinghai-Xizang (Tibet) plateau; the results will be published shortly. These surveys raised the extent and precision of geological information substantially. Classification and comparison of regional tectonic with the description of types, scales, attitudes and the distribution of folds and faults at the macro and meso scale, and of mineralization and metamorphism built a rich foundation for studying the tectonics of China in this book.

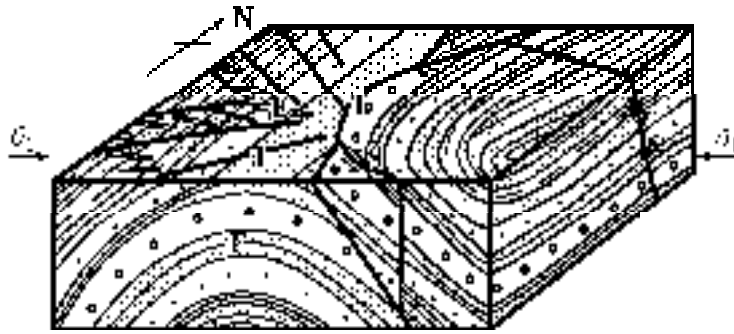


Fig. 1.5. Relationship between tectonic stress orientations and fold orientations.

(a)  $\sigma_1$  (horizontal), rightward movement, compression and denudation; (b)  $\sigma_2$  (vertical), down, compression and denudation; (c)  $\sigma_3$  (horizontal), leftward movement, extension and denudation; (d)  $\sigma_1$  (horizontal), leftward movement, extension and denudation; (e)  $\sigma_2$  (vertical), down, compression and denudation; (f)  $\sigma_3$  (horizontal), rightward movement, compression and denudation.

Data concerning the geometry and attitudes of ENE-WN and north-south folds (Fig. 10) in Appendix II have been collected and analyzed to determine regional tectonic stress orientations. In the case of the most of ENE-WN, where detailed geological surveys of the scale 1:200,000 have not yet been completed and detailed structural maps are available in detail, geological surveys at scales of 1:200,000 or 1:300,000 have been used and the strike-slip, related to anticlinal and synclinal. From these data, it can be seen that rock deformation on a widespread throughout the Chinese continent (the sphere of influence), the weak type of rock deformation can be found even in the youngest rocks throughout China, it is difficult to find an area not affected by rock deformation.

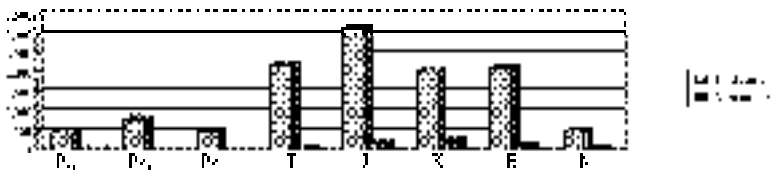


Fig. 1.6. Number of strike-slip faults in different regions: Neoproterozoic (P<sub>1</sub>-P<sub>3</sub>); Paleozoic (T); Mesozoic (J); Cenozoic (X, E); Quaternary (F). P<sub>1</sub>—Lower Palaeozoic (ca. 1.8W); Indusian (ca. 1.95W); Sinurian (ca. 1.9W-3S); Venetian (K); Q<sub>1</sub>—Quaternary (ca. 1.95E-1.5); Indusian (ca. 1.95W).

In all tectonic zones, rock deformation is mainly linear with Alpin type folds and, in cases with high and intermediate angles of dip for the faults, associated with many thrusts. In the plate areas covering half the size of China, there is a widespread deformation with inter-plate stresses, in which the angles of dip for faults are normally less than 20°, and the folds are associated with faults. These two types of deformation are transition types, belonging to the sedimentary cover detachment type, and may be called a new type of tectonic. Even in stable tectonic areas covering one-third of China which appear to have only horizontal tectonic stress, there are linear to type folds with faults with very low angles of dip, and normal faults with high angles of dip and complex joint systems.

### 1.4.3 The Kinematics of Blocks

The aim of tectonic studies is to examine rock deformation quantitatively, with the determination of the amounts of dilation (changes in volume), contraction (changes in shape) and translation (movements of the rock body as a whole) and the orientation of the stresses responsible for the deformation (Jin, 1993). In order to reach the determination of the rates of deformation (rates of strain) in horizontal and/or horizontal and vertical displacement, it may be necessary to manifest the effects of multiple phases of deformation, where the orientation of the stresses may have been different in each phase. This is relatively easy if the orientation of the stresses in each tectonic period was very different, but may be difficult or even impossible if these stresses were in the same, or nearly the same direction.

Research into the kinematics of the lithosphere is aimed at determining vertical movements of uplift and depression and horizontal movements of compression, extension and strike-slip movement, and the directions in which they were assumed.

Once attention has been concentrated on vertical movements of the lithosphere with the uplift and depression of Earth's surface, the determination of vertical movements during a stable tectonic period makes use of data on variations in sea level thickness, thickness of lithology and facies transition, and may also contribute to vertical movements. Vertical movements can be determined through the study of sedimentation and erosion, transgression and regression, the up-rise of magma or changes in the thickness of the lithosphere over long periods of time. During the last one hundred years, while new methods were being perfected, it was seen that vertical movements were the major kinematic feature of the kinematics of the lithosphere.

This hypothesis about the theoretical foundation for concepts of crustal expansion, limited plate tectonics, pan-tectonics, etc. (Wang, 1994) were recently hypothesized by Wang (Wu et al., 1994, 1995; Liang et al., 1995, 1996), up-lift of the Mesozoic to discontinue (Chen et al., 1992), up-lift of marine facies and three-stage tectonics or underthrusting (Dang et al., 1992, 1993, 1995, 1998), which have their bases in this earlier tectonic research, have exerted important influences over the development of tectonics in China. In these concepts, the tectonic evolution of continents takes place essentially as a result of vertical movements being the driving force for deformation and displacement, horizontal movements being secondary and limited in their extent. In these hypotheses, the importance of vertical movements has been more fully emphasized, in their accord with the possibility of near horizontal displacements over distances of several thousand kilometers. In these models, no explanation is offered at all for any possible horizontal displacements.

The importance of horizontal deformation and displacement was much more difficult to realize, and a model (one-plate tectonics) (Li, 1974; Wang et al., 1984, unpublished, 1995), first proposed the Theory of Continental Drift, based on the distribution of mass and indications of paleo-climatic zones. However, due to unexplained problems and some errors (e.g. it is impossible for the interior of continents to drift), the activities of several members of the Chinese Geographical Society (the Geographical Society of China) after detailed discussion of the International Geological Congress in 1972, the theory of continental drift was rejected. However, Wang's hypothesis was fundamentally correct and formed one of the foundations for the development of the theory of plate tectonics in the 1980s. This year also demonstrated the difficulty of carrying out entrenched scientific thought.

Methods for determining vertical and horizontal movements of the lithospheric plates are summarized in Table 1a.

The kinematics of the lithospheric plates differ according to the movements of the plates: high angle normal to reverse faults indicate vertical movements; intermediate and low angle faults indicate horizontal movements; characteristics of subduction or collisional tectonic zones and indicate horizontal tectonics; some low wrench (strike-slip) faults or transform faults indicate horizontal movements of the plates; intermediate and low angle normal and strike-slip or transform faults are characteristics of continental rift zones and oceanic ridges and indicate the oceanic extension of the plate.

Table 14 Basic and principles for various methodological examples

Geological phenomena	Methodological systems
	Basement uplift causes a reduction in thickness in post-orogenic basins Basin width change is determined by sedimentary pile thickness and subsidence amplitude
Changes of sedimentary thickness Tectonic position, tectonic evolution and sedimentary facies Basin type change of plate boundaries	Directional movement of sedimentary facies and <i>facies zone</i> Directional migration of tectonic boundaries Accretion and detachment zones
Magma and magma rock upflow and upburst of the crust The extension and contraction mechanism (P-T-t path) Plutonoids Highlands formation	Directional tectonic mechanism (extension-contraction) Tectonic belts Tectonic boundary and tectonic plate boundaries
High erosion in post-orogenic plateau areas and tectonic uplifts and faults	Directional tectonic uplift

Ramsay (1967), Royce and Fisher (1971) proposed a series of methods for determining the strain involved in fold or one unroofing, and made significant progress in this field. Some parameters and methods for determining vertical strain fields have not yet been developed, and it is difficult to determine rates of compression and extension using conventional methods of structural geology.

Suzuki (1996) first suggested that there was a correlation in between volatilities of plate composition and the chemical content:  $(\text{K}_2\text{O} + \text{Na}_2\text{O}) / (\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{SiO}_2)$  and silicon index  $(\text{Si} / (\text{Si} + \text{Al} + 4\text{O}))$  ( $\text{Na}_2\text{O} + \text{K}_2\text{O} / (\text{Al}_2\text{O}_3 + \text{SiO}_2)$ ) of volcanic rocks near the subduction zone. In the formula above, the unit of  $\text{Si}$  ( $\text{SiO}_2$ ) is the percentage of weight, the unit of  $\text{Al}$  ( $\text{Al}_2\text{O}_3$ ) is the percentage of molecules ( $\text{Al}^{3+}$ ). Using these parameters, Suzuki (1996) discovered that the silicon index increases with increasing rates of shortening, while Nagai and Kato later used it (Fig. 14.1).

This relationship is not linear, but has an exponential function. These relationships are due to the relationship of rates of silica and potassium to sodium. The rate ratio of silica is very small, while the rate ratio of potassium and sodium is relatively large. When the velocity of plate movement increases and tectonic accretion is enhanced, silica ions are enriched, while the ions of potassium and sodium decrease relatively (Sun et al., 1982, 1999). On the assumption that the velocities of movement involved in marginal and inner plate deformation are similar, the author (Wan 1994) has used the relationship derived from the study of plate margins to quantify tectonic movements. In general, velocities of movement during inner plate deformation would be less than the rates for marginal deformation. When the velocities of plate movement for the whole of these countries are discussed, on the basis of velocities calculated from plate margins, these velocities may be slightly exaggerated. However, all the data has been treated by the same method, so that the relative magnitudes of movement velocities for different areas are measurable.

Suzuki (1996) used only the relationship between the chemical content of volcanic rocks and the velocity of plate movement. The author has used, not only the chemical composition of volcanic rocks, but also that of intrusive rocks to estimate the velocities of plate movement, while volcanic and intrusive rocks were formed at the same time in the same tectonic series. The content of iron elements in intrusive rocks, especially  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{Al}_2\text{O}_3$ , is much lower than that of associated volcanic rocks. Wang (1994) has made such a comparison in numbers and found that the value of plate movement velocity calculated was the same or comparable using volcanic or intrusive rocks. Gao et al. (1985), Gao et al. (1986, 1987), Mo et al. (1991) and Ma et al. (1991, 1992) used Suzuki's method to estimate velocities of extension and compression of blocks in the Cenozoic volcanic areas of eastern China and of the Late Cenozoic volcanics in the Hengduanshan area. Using this method the



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